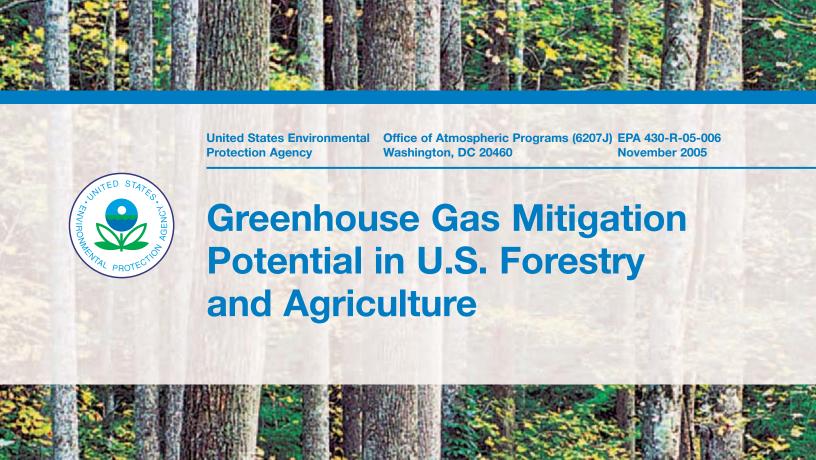
Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture

November 2005

Cover Page and Table of Contents

United States Environmental Protection Agency
Office of Atmospheric Programs (6207 J)
1200 Pennsylvania Avenue, NW
Washington, DC 20460







How to obtain copies

You can electronically download this document from U.S. EPA's web page at http://www.epa.gov/sequestration. To request free copies of this report, call the National Service Center for Environmental Publications (NSCEP) at 1 - (800) 490-9198.

For further information

For further information, contact Kenneth Andrasko, (202) 343-9281, andrasko.ken@epa.gov, or Benjamin DeAngelo, (202) 343-9107, deangelo.ben@epa.gov, U.S. Environmental Protection Agency.

Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture

November 2005

United States Environmental Protection Agency
Office of Atmospheric Programs (6207J)
1200 Pennsylvania Ave., NW
Washington, DC 20460



Acknowledgments This report was prepared under a contract between the U.S. Environmental Protection Agency (EPA) and RTI International. The main authors of the report are Brian C. Murray, Brent Sohngen, Allan J. Sommer, Brooks Depro, and Kelly Jones of RTI; Bruce McCarl of Texas A&M University and Dhazn Gillig of American Express Corporation; ² and Benjamin DeAngelo and Kenneth Andrasko of EPA. The report was edited by Kenneth Andrasko and Benjamin DeAngelo of EPA. The authors acknowledge the FASOMGHG model development efforts over the past decade of Darius Adams of Oregon State University; Ralph J. Alig of the USDA Forest Service in Corvallis, OR; John "Mac" Calloway, UNEP Risoe Centre on Energy, Climate and Sustainable Development; and Steven Winnett, EPA. We thank the following external reviewers: Richard Birdsey, USDA Forest Service; John Brenner, USDA Natural Resources Conservation Service; Suzie Greenhalgh, World Resources Institute; Cesar Izaurralde, Pacific Northwest National Laboratory; Jan Lewandrowski, USDA Office of the Chief Economist; Ruben Lubowski, USDA Economic Research Service; Michelle Manion, Union of Concerned Scientists; Reid Miner, National Council for Air and Stream Improvement; Sian Mooney, University of Wyoming; Keith Paustian, Colorado State University; Neil Sampson, The Sampson Group; Ron Sands, Pacific Northwest National Laboratory; and Tristram West, Oak Ridge National Laboratory. We also thank other EPA reviewers: Steven Rose, Francisco de la Chesnaye, Dina Kruger, Allen Fawcett, and John Powers. Research assistance was provided by Laurel Clayton and Catherine Corey of RTI. Sharon Barrell of RTI coordinated editing and publications support. ¹ Dr. Sohngen was on sabbatical from The Ohio State University when working on this report at RTI. ² Dr. Gillig was at Texas A&M University when she performed this work.

Table of Contents

Acknowledgments	
Table of Contents	ii
List of Tables, Figures, and Boxes	vi
Tables	vi
Figures	vii
Boxes	
Executive Summary	ES-1
1. Introduction	1-1
Purpose and Approach of this Report	1-3
Organization of Report	
2. Greenhouse Gas Mitigation Options in U.S. Forestry and Agriculture	
Chapter 2 Summary	2-1
Carbon Sequestration	2-1
Afforestation	2-2
Forest Management	2-2
Agricultural Soil Carbon Sequestration	
Grassland Conversion	
Grazing Management	
Riparian Buffers	2-6
GHG Emissions Reduction Options in Agriculture	2-6
Reduction of CO ₂ Emissions from Fossil Fuel Use	2-6
Reduction of Non-CO ₂ GHG Emissions	
Biofuel Offsets of Fossil Fuels	2-9
Unique Time Dynamics of Carbon Sequestration Options	2-9
"Saturation" of Carbon Sequestration to Equilibrium	2-9
Reversibility of Carbon Sequestration	2-11
Accounting for Carbon after Timber Harvests	2-12
Addressing Carbon Sequestration Dynamics in this Report	2-12

3.	Modeling Framework and Baseline	
	Chapter 3 Summary	3-1
	Modeling Framework	3-1
	General Model Description	3-2
	Geographic Coverage/Regional Detail	3-4
	Land Base	3-4
	General Economic Concepts: Optimizing Behavior	3-4
	Forest-Sector Economic Detail	3-6
	Agriculture-Sector Economic Detail	3-8
	Biofuels	3-9
	Cross-Sector Land Interaction	3-10
	Greenhouse Gas Accounting	3-10
	Non-GHG Environmental Indicators	3-13
	GHG Mitigation Strategies	3-13
	Baseline GHG Projections from the Forest and Agriculture Sectors	3-15
	FASOMGHG Baseline Projections.	3-15
	Comparison of FASOMGHG Baseline GHG Projection to Other Published Estima	ites 3-19
	Applying FASOMGHG for the Purposes of this Report	3-24
4.	Mitigation Potential: Comprehensive Scenarios with All Activities and All GHGs	4-1
	Chapter 4 Summary.	4-1
	Mitigation Responses under Various GHG Mitigation Scenarios	4-2
	Scenarios Description: Constant and Rising Incentives for GHG Mitigation	
	Mitigation Response to Constant GHG Price Scenarios	
	Mitigation Response to Rising GHG Price Scenarios	4-18
	Comparison of FASOMGHG Results with Other Analyses	4-21
	Richards and Stokes (2004): Forest Carbon	4-21
	Stavins (1999): Afforestation	4-22
	Sedjo, Sohngen, and Mendelsohn (2001): Forest Carbon	4-23
	USDA, Economic Research Service (2004): Agricultural Carbon Sequestration	4-24
	Recap of Study Comparisons	4-24
	Appendix 4.A	4-25

5.	Mitigation Potential of Selected Activities5-	-1
	Chapter 5 Summary5-	-1
	Fixed Quantities of National GHG Mitigation5-	-2
	National-Level Results by Activity and Time Period5-	-2
	Regional Activity Contributions to National Mitigation Levels	-7
	National Mitigation Quantity Scenarios Summary5-	-8
	Limiting Payments by GHG Type	-8
	Paying for CO ₂ Only vs. Paying for All GHGs: \$15/t CO ₂ Eq	-8
	CO ₂ Only: Mitigation Over Time	-9
	Selected Activity Scenarios5-	-9
	National Results5-1	1
	Regional Results	11
6.	Implications of Mitigation via Selected Activities6-	-1
	Chapter 6 Summary6-	-1
	Project Quantification Issues and Costs	-2
	Quantifying the Net GHG Contribution of Projects	-2
	Other Project Implementation Considerations	11
	Preliminary Assessment of Implementation Factors by Major Mitigation Activity 6-1	13
	Per-Acre Payments for Carbon Sequestration to Address Measurement Difficulties 6-1	14
	Scenario Description. 6-1	14
	Per-Acre Payments for Carbon Sequestered through Afforestation 6-1	۱6
	Per-Acre Payments for Agricultural Soil Carbon Sequestered through Changes in Tillage6-1	17
7.	Non-GHG Environmental Co-effects of Mitigation7-	
	Chapter 7 Summary	
	Land Use	- 1
	Regional Distribution of Land Uses	
	Timberland Management Intensity	
	Agricultural Nonpoint Pollutant Runoff7-	-5
	Changes in Agricultural Runoff and Water Quality—Results from a Separate Case Study7-	-8
	Implications for Biodiversity of GHG Mitigation	11

8.	Summary of Insights on Key GHG Mitigation Issues	.8-1
	Key Issues	. 8-1
	Insights from Analyzed Results.	. 8-2
	While national mitigation rates decline over time (under constant price scenarios), cumulative GHG mitigation steadily increases	. 8-2
	Identifying attractive activities may require looking at a range of characteristics for each option	. 8-3
	The quantity and timing of mitigation can determine the selected activities	. 8-3
	Achieving a specific mitigation level within a narrow time frame may shift emissions to periods before and after the period of interest.	. 8-3
	Under scenarios of rising GHG payments, forest and agriculture mitigation action may be delayed	. 8-6
	GHG incentives reduce net emissions from the forest and agriculture sectors below baseline levels. If the incentives are strong enough, the joint sectors could move from a net emissions source to a sink	. 8-6
	Leakage potential from limiting included mitigation activities may be largely confined to the forest sector.	. 8-7
	Raising GHG mitigation levels in forestry and agriculture can cause environmental co-effects, both good and bad.	. 8-8
	Payment method will determine efficiency of mitigation activities	. 8-8
	If outreach is needed to deliver GHG mitigation, these efforts might focus in regions with the largest mitigation potential.	. 8-9
0	Deferences	D 4

List of Tables, Figures, and Boxes

Tables

Table 2-1:	Representative Carbon Sequestration Rates and Saturation Periods for Key Agriculture, Land-Use Change, and Forestry Practices	2-3
Table 2-2:	Agricultural Non-CO ₂ Emissions by Source, 2003 (Tg CO ₂ Eq.)	2-7
Table 3-1:	FASOMGHG Model: Key Dimensions	3-3
Table 3-2:	FASOMGHG Regional Definitions	3-5
Table 3-3:	Agriculture-Sector Commodities	3-8
Table 3-4:	GHG Emission Sources and Sinks in FASOMGHG	. 3-11
Table 3-5:	Broad GHG Mitigation Strategies Covered in FASOMGHG	. 3-13
Table 3-6:	Mitigation Options Not Explicitly Captured in FASOMGHG	. 3-14
Table 3-7:	U.S. Land-Use Change for Major Categories: 1982–1997	. 3-16
Table 3-8:	Baseline Forest and Agriculture GHG Net Annual Emissions by Activity and Decade for the United States: FASOMGHG Model: 2010–2050	. 3-18
Table 3-9:	Net Annual CO ₂ Flux from U.S. Forest Carbon Stocks: 1990 and 2000, EPA Inventory Quantities (in Tg CO ₂ per year)	. 3-20
Table 3-10:	Projected Net CO ₂ Flux from U.S. Forest Carbon Stocks: 1990–2040, USDA Forest Service Estimate	. 3-20
Table 3-11:	Non-CO ₂ GHG Emissions from Agriculture (Tg CO ₂ Eq.): EPA GHG Inventory, 1990–2003	. 3-23
Table 4-1:	Core Price Scenarios.	4-3
Table 4-2:	CO ₂ and C Price Equivalents	4-3
Table 4-3:	Acreage Converted from Conventional Tillage to Reduced Tillage under Baseline and GHG Prices: U.S. Total (Million acres)	4-7
Table 4-4:	Comparison of Annualized GHG Mitigation Estimates (Tg CO ₂ Eq. per year) across Alternative Time Horizons at a GHG Price of \$15/t CO ₂ Eq	. 4-11
Table 4-5:	National GHG Mitigation Totals by Activity: Annualized Averages, 2010–2110	. 4-12
Table 4-6:	Top 10 Region-Activity Mitigation Combinations	. 4-17
Table 4-7:	Comparison of FASOMGHG Results in this Chapter to Range of Estimates from Richards and Stokes' (2004) Review Study	. 4-21

Table 4-8:	Comparison of FASOMGHG Results in this Chapter to Stavins' (1999) Study 4-22
Table 4-9:	Comparison of FASOMGHG Forest Carbon Sequestration Results in this Chapter with Sedjo, Sohngen, and Mendelsohn (2001)
Table 4-10:	Comparison of this Study with Lewandrowski et al. (2004) (USDA ERS) 4-24
Table 4.A.1:	Key Results at the National Level by Activity, Time Period, and Constant-Price Scenarios
Table 4.A.2:	Total Forest and Agricultural GHG Mitigation by Region 4-26
Table 4.A.3:	Forest and Agricultural GHG Mitigation by Activity, Region, and Price Scenario 4-26
Table 4.A.4:	Key Results at the National Level by Activity, Time Period, and Rising Price Scenarios
Table 5-1:	National GHG Mitigation Quantity Scenarios for 2025 and 2055
Table 5-2:	National Mitigation, by Scenario and Activity, for Least-Cost Quantity in 2025 and 2055: Annualized over 2010–2110
Table 5-3:	Least-Cost Mitigation Response to Fixed National GHG Mitigation Levels in 2015, 2025, and 2055
Table 5-4:	GHG Mitigation Quantity Ranking by Region/Activity Combination: Fixed National Mitigation Quantity Scenarios
Table 5-5:	Mitigation Quantities: Payments for CO ₂ Only vs. Payment for All GHGs (\$15 per t CO ₂ Eq.)
Table 5-6:	National GHG Mitigation Totals in Key Years by Activity: Payment for CO ₂ Only at \$15/t CO ₂ Eq. (Includes Non-CO ₂ GHGs)
Table 5-7:	Selected Activity Scenarios
Table 5-8:	GHG Mitigation under Payment for Specific Activity Scenarios 5-11
Table 6-1:	Candidate Approaches for Accounting for Reversal Risk from Carbon-Based GHG Mitigation Projects
Table 6-2:	Leakage Estimates by Mitigation Activity at a GHG Price of \$15/t CO ₂ Eq 6-6
Table 6-3:	Afforestation Regional Leakage Estimates from Murray et al. (2004) 6-9
Table 6-4:	Forest Preservation and Avoided Deforestation Regional Leakage Results from Murray et al. (2004)
Table 6-5:	Implementation Issues for Selected Activities and Projects: Leakage Estimates from FASOMGHG and MMV

Table 6-6:	Qualitative Consideration of Implementation Issues for Selected Activities and Projects: Baselines, Additionality, and Reversal Risk
Table 6-7:	Per-Acre vs. Per-Tonne Payment Approaches for Afforestation: 2015 and 2010–2110 Annualized
Table 6-8:	Agricultural Soil Carbon Sequestration Payment Approaches: 2015 and 2010–2110 Annualized
Table 7-1:	Land Use under the Baseline, \$15, and \$50 (Constant) GHG Price Scenarios: 2015 and 2055
Table 7-2:	Change in Pollutant Loadings for Selected Agricultural Pollutants and the WQI for the $\$6.80$ per tonne CO_2 Eq. Scenario, using the ASMGHG-NWPCAM Model Integration
Table 8-1:	Characteristics of GHG Mitigation Activities8-4
Table 8-2:	Potential Implications of Mitigation Level and Time Frame
Table 8-3:	Leakage Estimates by Mitigation Activity at a GHG Price of \$15/t CO ₂ Eq 8-7
Figures	
Figure 1-1:	Forestry and Agriculture Net Contribution to GHG Emissions in the United States, 2003
Figure 2-1:	Agricultural Non-CO ₂ Emissions by Source Relative to All Other GHG Emissions 2-7
Figure 2-2:	Conceptual Model of Soil Organic Matter Decomposition and Accumulation Following Disturbance
Figure 2-3:	Absolute Change in the Annual Rate of Carbon Sequestered Following a Change from Conventional Tillage (CT) to No-Till (NT)
Figure 2-4:	Carbon Accumulation on an Afforested Stand to Saturation
Figure 2-5:	Cumulative Carbon Changes for a Scenario Involving Afforestation and Harvest 2-12
Figure 3-1:	FASOMGHG Regions
Figure 3-2:	FASOMGHG Market Linkages
Figure 3-3:	Cumulative Carbon Changes for a Scenario Involving Afforestation and Harvest 3-12
Figure 3-4:	Baseline Land-Use Projections, FASOMGHG: 2010–2050 (Million acres)
Figure 3-5:	Total Factor Productivity in U.S. Agriculture: 1949–1998
Figure 3-6:	Forest and Agriculture Products Price Series

Figure 3-7:	Comparison of Projected Baseline Carbon Sequestration Trends in U.S. Forests: FASOMGHG vs. USDA Forest Service Model
Figure 3-8:	Comparison of Projected Baseline Non-CO ₂ GHG: FASOMGHG vs. Scheehle and Kruger (in press)
Figure 4-1:	Price Trajectories for Rising-Price Scenarios
Figure 4-2:	Land Use in 2025 at Different GHG Price Levels
Figure 4-3:	Timberland Area over Time: \$50/t CO ₂ Eq. vs. Baseline
Figure 4-4:	Effect of GHG Prices on Forest Management Variables, 2015
Figure 4-5:	National GHG Mitigation at Representative Years by Price (2015, 2025, and 2055) 4-8
Figure 4-6:	Cumulative GHG Mitigation over Time
Figure 4-7:	Comparison of Actual, Cumulative Average, and Annualized GHG Mitigation Value Calculations at \$15/t CO ₂ Eq.: 2010–2110
Figure 4-8:	GHG Mitigation Supply Function from National GHG Mitigation Totals by Activity
Figure 4-9:	Model Sensitivity to Saturation Period toward a New Soil Carbon Equilibrium from Tillage Change: GHG Price = \$15/t CO ₂ Eq
Figure 4-10:	Sensitivity of Model Results to Assumed Biofuel Demand Restrictions: GHG Price = $$30/t$ CO ₂ Eq
Figure 4-11:	Total Forest and Agriculture GHG Mitigation by Region
Figure 4-12:	Pollutant Loading Effects Over Time of a \$15/t CO ₂ Eq. GHG Price 4-18
Figure 4-13:	Constant-Price Scenarios vs. Rising-Price Scenarios and GHG Mitigation 4-19
Figure 4-14:	Cumulative GHG Mitigation over Time: \$3/t CO ₂ Price Rising at Two Rates 4-20
Figure 4-15:	Cumulative GHG Mitigation over Time: \$20/t CO ₂ Price Rising by \$1.30 per Year (\$75 cap)
Figure 5-1:	Least-Cost Mitigation Quantities by Scenario and Activity in 2025 and 2055 5-3
Figure 5-2:	Scenarios with Objective of Mitigating: (a) 375 Tg $\rm CO_2$ Eq. in 2025 and Maintaining; (b) 375 in 2025 and 900 Tg $\rm CO_2$ Eq. in 2055; and (c) 375 Tg $\rm CO_2$ Eq. in 2025 without Maintaining Thereafter
Figure 5-3:	Cumulative Mitigation: Payment for CO ₂ Only (Includes Non-CO ₂ GHGs) vs. All GHGs at \$15/t CO ₂ Eq
Figure 5-4:	GHG Mitigation under Payments for Afforestation and Forest Management Only at \$15/t CO ₂ Eq.: By Region

Figure 5-5:	GHG Mitigation under Payments for Biofuel Offsets Only at \$3/t CO ₂ Eq., Rising at 4 Percent per Year, By Region
Figure 5-6:	GHG Mitigation by Region and Activity under Payments for Agricultural Management Only: \$15/t CO ₂ Eq
Figure 5-7:	Regional Distribution of Soil Carbon Sequestration under Payment for Soil Carbon Only: \$15/t CO ₂ Eq. Constant Price
Figure 6-1:	Regional Leakage Flows for Afforestation-Only Payment Scenario: \$15/t CO ₂ Eq 6-8
Figure 6-2:	Regional Shares of Afforestation Carbon Sequestration by Payment Approach 6-17
Figure 6-3:	Regional Shares of Agricultural Soil Carbon Sequestration by Payment Approach 6-18
Figure 7-1a:	Land-Use Allocation by Eastern U.S. Regions in 2015: Baseline and the \$15 and \$50 Constant GHG Price Scenarios
Figure 7-1b:	Land-Use Allocation by Eastern U.S. Regions in 2055: Baseline and the \$15 and \$50 Constant GHG Price Scenarios. 7-3
Figure 7-2a:	Land-Use Allocation by Western U.S. Regions in 2015: Baseline and the \$15 and \$50 Constant GHG Price Scenarios
Figure 7-2b:	Land-Use Allocation by Western U.S. Regions in 2055: Baseline and the \$15 and \$50 Constant GHG Price Scenarios
Figure 7-3:	Soil Erosion Index over Time by (Constant) GHG Price Scenario (Baseline = 100) 7-6
Figure 7-4:	Phosphorous Loading Index over Time by (Constant) GHG Price Scenario (Baseline = 100)
Figure 7-5:	Nitrogen Runoff Index over Time by (Constant) GHG Price Scenario (Baseline = 100)
Figure 7-6:	Pesticide Index over Time by (Constant) GHG Price Scenario (Baseline = 100) 7-8
Figure 7-7:	Changes in Water Quality from Soil Carbon Sequestration and Other Agricultural Management Changes under $\$6.8$ per Tonne CO_2 Scenario in ca. 2020, using the ASMGHG-NWPCAM Integrated Agriculture Water Quality Model 7-10
Figure 8-1:	National GHG Mitigation at Three Focus Dates by GHG Price: Average Annual 8-2
Figure 8-2:	Cumulative GHG Mitigation in Tg CO ₂ Eq8-3
Figure 8-3:	Responses to Set Mitigation Quantities: Cumulative Mitigation to 2100 8-5
Figure 8-4:	Constant Price Scenarios vs. Rising Price Scenarios and GHG Mitigation 8-6
Figure 8-5:	Cumulative Net Emissions/Sinks for Forestry and Agriculture: Comparison of Baseline and Comprehensive Mitigation Scenarios at Constant Prices over Time 8-7

	Figure 8-6:	Nitrogen Runoff Index over Time by (Constant) GHG Price Scenario
	Figure 8-7:	Total Forest and Agriculture GHG Mitigation by Region 8-9
3	oxes	
	Box 1-1:	Relative Global Warming Potential of Non-CO ₂ Gases
	Box 3-1:	Perfect Foresight in Climate Economic Models
	Box 4-1:	Measurement Units Reported in the Analysis
	Box 4-2:	Methods Used for Reporting GHG Mitigation Results at Different Points in Time 4-3
	Box 4-3:	Technical, Economic, and Competitive Potential of a GHG Mitigation Option 4-5
	Box 4-4:	Summary of Constant GHG Price Scenario Results
	Box 4-5:	Annualizing Results over the Projection Period 4-10
	Box 4-6:	Sensitivity Analysis of Key Assumption: Time to Reach Soil Carbon Equilibrium ("Saturation")
	Box 4-7:	Sensitivity Analysis of Key Assumption: Biofuel Demand 4-15
	Box 6-1:	Shortening the Time Horizon for Quantifying Leakage 6-7